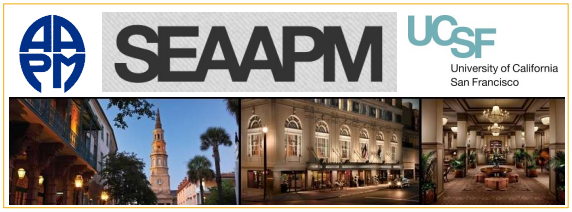
Spinal SBRT

Timothy D. Solberg, PhD
Professor and Vice Chair
Division of Medical Physics
University of California, San Francisco



SEAAPM SYMPOSIUM & SCIENTIFIC MEETING FEB. 23-25, 2017

The Beginning of SBRT

Reproducibility 5-8 mm for 90% of setups
Diaphragmatic movement limited to 5-10 mm with pressure.

Lax et al, Acta Oncol. 33:677-83, 1994

Original clinical report (1995) of first 31 patients, primarily solitary tumors in the liver and lung. Doses from 7 to 45 Gy in 1 to 4 fractions.

Blomgren et al, Acta Oncol. 34:861-70, 1995

Setup accuracy evaluated in 30 patients using CT and port films; conclude that a 5 mm margin for PTV is sufficient if CT is performed prior to every treatment. Deviation of < 10 mm (AP and Lat) in 98% of targets.

Not Good Enough

Wulf et al, Radiotherapy Oncology 55:225-236, 2000

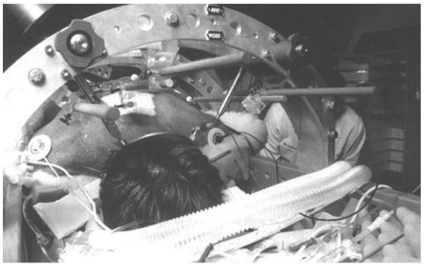
1995 – 1st successful spinal radiosurgery

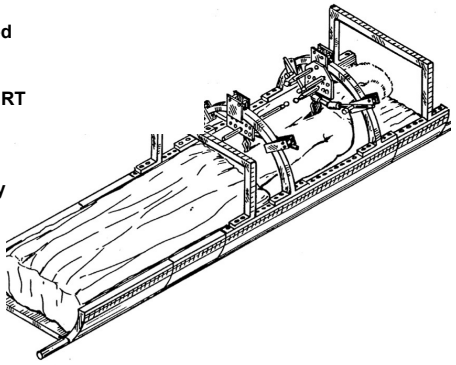
Rigid skeletal fixation above and below the involved segments

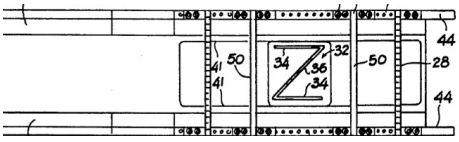
Linac delivery with circular collimators / arcs or IMRT

System accuracy ≤ 2.0 mm

8-10 Gy Rx with no portion of cord receiving > 3 Gy







US005281232A

United States Patent [19]
Hamilton et al.

[11] Patent Number: 5,281,232
[45] Date of Patent: Jan. 25, 1994

[54] REFERENCE FRAME FOR STEREOTACTIC RADIOSURGERY USING SKELETAL FIXATION

[75] Inventors: Allan J. Hamilton; Bruce A. Lulu, both of Tucson, Ariz.

[57] ABSTRACT

A body-support frame comprising a horizontal table having two adjustable braces that can be moved along the main axis of the table for straddling a patient lying within the frame. Each brace is equipped with a swiv-

Hamilton et al, Neurosurgery 36; 311-319, 1995

Spine Mets - Why Radiosurgery?

Effective treatment for oligometastatic disease

Fewer fractions, more convenient, shorter break from chemotherapy

Higher doses should be more effective

Faster, more durable palliation

Less normal tissue irradiated

Ability to retreat

But ……

Technically challenging, little margin for error, paucity of data on cord tolerance to single fraction

Other potential complications include: mucositis, laryngitis, esophageal stricture, and compression fracture

Gerszten *et al. Radiation Oncology* 2013, **8**:158
http://www.ro-journal.com/content/8/1/158

RADIATION ONCOLOGY

SHORT REPORT Open Access

A multi-national report on methods for institutional credentialing for spine radiosurgery

Peter C Gerszten[1,8*], Arjun Sahgal[2], Jason P Sheehan[3], Ronald Kersh[4], Stephanie Chen[1], John C Flickinger[1], Mubina Quader[1], Daniel Fahim[5], Inga Grills[5], John H Shin[6], Brian Winey[6], Kevin Oh[6], Reinhart A Sweeney[7] and Matthias Guckenberger[7]

7 Participating Institutions

24 item questionnaire covering 5 broad areas:

(1) policies and procedures,
(2) training requirements,
(3) surgeon involvement,
(4) the role of industry and professional organizations,
(5) perceptions regarding the importance of credentialing requirements.

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Strong Agreement

- Formal credentialing process for all physicians, physicists, and therapists;
- Need for a written policy specific for spine radiosurgery credentialing;
- Reliance upon in-house proctoring system for physicians, physicists, and therapists;
- Credentialing should be device specific;
- Professional organizations develop guidelines for institutions credentialing requirements;
- Importance of credentialing for safety and clinical outcomes.

Some Agreement

- Requirement to have more than one specialist trained to perform spine radiosurgery as a back up.

Clinical practice of image-guided spine radiosurgery - results from an international research consortium

Matthias Guckenberger[1*], Reinhart A Sweeney[1], John C Flickinger[2,3], Peter C Gerszten[2,4], Ronald Kersh[5,6], Jason Sheehan[7] and Arjun Sahgal[8] *Radiation Oncology* 2011, **6**:172

	UHW	UPMC	UofT	UVAMC	RSMC
Use of single fraction radiosurgery	No, all patients are treated with either five or ten fractions	Single fraction radiosurgery for 95% of the patients unless very near to spinal cord.	Majority is treated with two or three fractions and specific cases for single fraction	Majority is treated with a single fraction of radiosurgery, occasionally up to 3 fractions	No, majority are treated with three fractions with treatments given one week apart.
Criteria for selection of hypo-fractionated regimes	Selection of fractionation scheme based on life expectancy using the Mizumoto Score		Fractionated protocols in: 1. Epidural disease or large volume and no prior irradiation 2. Prior radiation	Fractionated protocols after prior radiation	If it represents the only site of disease, we use 30 Gy in 3
Schema 1: # fractions and single fraction dose	Good life expectancy: 30 Gy in 10: PTV-elective 48.5 Gy in 10: PTV -macroscopic *	16-24 Gy in 1; Most frequently 17 Gy in 1	20-24 Gy in 1; Most frequently 20 Gy in 1	18 to 24 Gy in 1; Most frequently 20 Gy in 1	24 Gy in 3
Schema 2: # fractions and single fraction dose	Intermediate life expectancy: 20 Gy in 5: PTV-elective 35 Gy in 5: PTV -macroscopic *		24 - 27 Gy in 2-3	24 Gy in 3	30 Gy in 3
Schema 3: # fractions and single fraction dose			30 Gy in 3 (for sarcomas)	18 Gy in 3	

Clinical practice of image-guided spine radiosurgery - results from an international research consortium

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Tolerance doses Spinal Cord

	Dosimetric parameter	Single fraction	3 fractions	5 fractions	10 fractions
UHW	Dmax to 0.1 cc			23.75 Gy	35 Gy
UPMC	Dmax	11 Gy	18 Gy		
UofT	Dmax	10 Gy	17.5 Gy	22 Gy	
UVAMC	D10	10 Gy	15 Gy	20 Gy	
RSMC	2 cc		18 Gy		

Tolerance doses Cauda equina

	Dosimetric parameter	Single fraction	3 fractions	5 fractions	10 fractions
UHW	Dmax to 0.1 cc			25 Gy	37.5 Gy
UPMC	Dmax	12 Gy	18 Gy		
UofT	Dmax	12 Gy	18 Gy	23 Gy	
UVAMC	D10	12 Gy	15 Gy	20 Gy	
RSMC	2 cc		24 Gy		

Clinical practice of image-guided spine radiosurgery

	UHW	UPMC	UofT	UVAMC	RSMC
Imaging modality, which is used for GTV definition	MRI and CT	MRI and CT, FDG-PET if available	MRI and CT	CT and MRI	CT, MRI and FDG-PET
Use of an anatomical target volume concept	Anatomical two dose-level target volume concept	Anatomical target volume concept	Anatomical target volume concept	Anatomical target volume concept	Anatomical target volume concept
GTV to PTV safety margin	3 mm	2 mm; 3 mm in the sacrum.	2 mm	2 mm	None
Protocol if PTV overlaps with the. spinal cord	Two dose-level approach; The OAR spinal cord is always in the PTV-elective and is always excluded from the higher dose PTV-macroscopic	PTV within 1 mm to the spinal cord is excluded from the PTV	PTV is limited by the cord or thecal sac for cauda equina	If this occurs, we either operate to resect part of the tumor or fractionate the radiation.	GTV drawn to edge of OAR
Treatment of the vertebra superior and inferior to the metastatic vertebra	No	No	No	No	No
Imaging modality for definition of the spinal cord	Spinal cord in MRI	Spinal cord in MRI	Spinal cord in MRI	Spinal cord in MRI	Spinal canal in CT
Delineation of the spinal cord in cranio-caudal direction	At least 1 level above and below PTV	1 level above and below PTV	At least 1 level above and below PTV	1 level above and below PTV	1 level above and below PTV
Safety margins around the spinal cord in axial directions	1 mm	1 mm	1.5 mm	No	2 mm anterior and 1 mm lateral
Delineation of the cauda equina	Thecal sac	Thecal sac	Thecal sac	Thecal sac	Thecal sac

Timmerman Dose Constraints

Serial Tissue	Volume (mL)	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
SINGLE-FRACTION TREATMENT				
Optic pathway	<0.2	8	10	Neuritis
Cochlea			12	Hearing loss
Brainstem	<1	10	15	Cranial neuropathy
Spinal cord	<0.25	10	14	Myelitis
	<1.2	7		
Cauda equina	<5	14	16	Neuritis
Sacral plexus	<3	14.4	16	Neuropathy
Esophagus*	<5	14.5	19	Stenosis/fistula
Ipsilateral brachial plexus	<3	14.4	16	Neuropathy
Heart/pericardium	<15	16	22	Pericarditis
Great vessels	<10	31	37	Aneurysm
Trachea and ipsilateral bronchus*	<4	8.8	22	Stenosis/fistula
Skin	<10	14.4	16	Ulceration
Stomach	<10	13	16	Ulceration/fistula
Duodenum*	<5	8.8	16	Ulceration
Jejunum/ileum*	<5	9.8	19	Enteritis/obstruction
Colon*	<20	11	22	Colitis/fistula
Rectum*	<20	11	22	Proctitis/fistula
Bladder wall	<15	8.7	22	Cystitis/fistula
Penile bulb	<3	14	34	Impotence
Femoral heads (right and left)	<10	14		Necrosis
Renal hilum/vascular trunk	<2/3 volume	10.6		Malignant hypertension

Parallel Tissue	Critical Volume (mL)	Critical Volume Dose Max (Gy)	Endpoint (≥Grade 3)
Lung (right and left)	1,500	7	Basic lung function
Lung (right and left)	1,000	7.4	Pneumonitis
Liver	700	9.1	Basic liver function
Renal cortex (right and left)	200	8.4	Basic renal function

Timmerman et al, Sem Rad Onc, 2008

Timmerman Dose Constraints

Serial Tissue	Volume (mL)	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
THREE-FRACTION TREATMENT				
Optic pathway	<0.2	15 (5 Gy/fx)	19.5 (6.5 Gy/fx)	Neuritis
Cochlea			20 (6.67 Gy/fx)	Hearing loss
Brainstem	<1	18 (6 Gy/fx)	23 (7.67 Gy/fx)	Cranial neuropathy
Spinal cord	<0.25	18 (6 Gy/fx)	22 (7.33 Gy/fx)	Myelitis
	<1.2	11.1 (3.7 Gy/fx)		
Cauda equina	<5	21.9 (7.3 Gy/fx)	24 (8 Gy/fx)	Neuritis
Sacral plexus	<3	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Esophagus*	<5	21 (7 Gy/fx)	27 (9 Gy/fx)	Stenosis/fistula
Ipsilateral brachial plexus	<3	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Heart/pericardium	<15	24 (8 Gy/fx)	30 (10 Gy/fx)	Pericarditis
Great vessels	<10	39 (13 Gy/fx)	45 (15 Gy/fx)	Aneurysm
Trachea and ipsilateral bronchus*	<4	15 (5 Gy/fx)	30 (10 Gy/fx)	Stenosis/fistula
Skin	<10	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Ulceration
Stomach	<10	21 (7 Gy/fx)	24 (8 Gy/fx)	Ulceration/fistula
Duodenum*	<5	15 (5 Gy/fx)	24 (8 Gy/fx)	Ulceration
Jejunum/ileum*	<5	16.2 (5.4 Gy/fx)	27 (9 Gy/fx)	Enteritis/obstruction
Colon*	<20	20.4 (6.8 Gy/fx)	30 (10 Gy/fx)	Colitis/fistula
Rectum*	<20	20.4 (6.8 Gy/fx)	30 (10 Gy/fx)	Proctitis/fistula
Bladder wall	<15	15 (5 Gy/fx)	30 (10 Gy/fx)	Cystitis/fistula
Penile bulb	<3	21.9 (7.3 Gy/fx)	42 (14 Gy/fx)	Impotence
Femoral heads (right and left)	<10	21.9 (7.3 Gy/fx)		Necrosis
Renal hilum/vascular trunk	<2/3 volume	18.6 (6.2 Gy/fx)		Malignant hypertension
Parallel Tissue	**Critical Volume (mL)**	**Critical Volume Dose Max (Gy)**		**Endpoint (≥Grade 3)**
Lung (right and left)	1,500	10.5 (3.5 Gy/fx)		Basic lung function
Lung (right and left)	1,000	11.4 (3.8 Gy/fx)		Pneumonitis
Liver	700	17.1 (5.7 Gy/fx)		Basic liver function
Renal cortex (right and left)	200	14.4 (4.8 Gy/fx)		Basic renal function

Timmerman et al, Sem Rad Onc, 2008

Timmerman Dose Constraints

Serial Tissue	Volume (mL)	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
FIVE-FRACTION TREATMENT				
Optic pathway	<0.2	20 (4 Gy/fx)	25 (5 Gy/fx)	Neuritis
Cochlea			27.5 (5.5 Gy/fx)	Hearing loss
Brainstem	<1	26 (5.2 Gy/fx)	31 (6.2 Gy/fx)	Cranial neuropathy
Spinal cord	<0.25	22.5 (4.5 Gy/fx)	30 (6 Gy/fx)	Myelitis
	<1.2	13.5 (2.7 Gy/fx)		
Cauda equina	<5	30 (6 Gy/fx)	34 (6.4 Gy/fx)	Neuritis
Sacral plexus	<3	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Esophagus*	<5	27.5 (5.5 Gy/fx)	35 (7 Gy/fx)	Stenosis/fistula
Ipsilateral brachial plexus	<3	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Heart/pericardium	<15	32 (6.4 Gy/fx)	38 (7.6 Gy/fx)	Pericarditis
Great vessels	<10	47 (9.4 Gy/fx)	53 (10.6 Gy/fx)	Aneurysm
Trachea and ipsilateral bronchus*	<4	18 (3.6 Gy/fx)	38 (7.6 Gy/fx)	Stenosis/fistula
Skin	<10	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Stomach	<10	28 (5.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration/fistula
Duodenum*	<5	18 (3.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Jejunum/ileum*	<5	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	enteritis/obstruction
Colon*	<20	25 (5 Gy/fx)	38 (7.6 Gy/fx)	colitis/fistula
Rectum*	<20	25 (5 Gy/fx)	38 (7.6 Gy/fx)	proctitis/fistula
Bladder wall	<15	18.3 (3.65 Gy/fx)	38 (7.6 Gy/fx)	cystitis/fistula
Penile bulb	<3	30 (6 Gy/fx)	50 (10 Gy/fx)	Impotence
Femoral heads (right and left)	<10	30 (6 Gy/fx)		Necrosis
Renal hilum/vascular trunk	<2/3 volume	23 (4.6 Gy/fx)		Malignant hypertension
Parallel Tissue	**Critical Volume (mL)**	**Critical Volume Dose Max (Gy)**		**Endpoint (≥Grade 3)**
Lung (right and left)	1,500	12.5 (2.5 Gy/fx)		Basic lung function
Lung (right and left)	1000	13.5 (2.7 Gy/fx)		Pneumonitis
Liver	700	21 (4.2 Gy/fx)		Basic liver function
Renal cortex (right and left)	200	17.5 (3.5 Gy/fx)		Basic renal function

*Avoid circumferential irradiation.

Timmerman et al, Sem Rad Onc, 2008

Contents lists available at ScienceDirect

Cancer Treatment Reviews

journal homepage: www.elsevierhealth.com/journals/ctrv

Cancer Treatment Reviews 37 (2011) 567–578

Stereotactic radiosurgery and hypofractionated stereotactic radiotherapy: Normal tissue dose constraints of the central nervous system

Michael T. Milano[a,*], Kenneth Y. Usuki[a,1], Kevin A. Walter[b,2], Douglas Clark[a,1], Michael C. Schell[a,1]

Structure	Outcome	Constraint
Brain parenchyma[a]	Necrosis	Tissue V12 <5–10 ml Tissue V10 <10 ml
Brainstem	Necrosis or neurologic deficits	<10–12 Gy maximum
Optic nerve/optic chiasm	Vision loss, anopsia, decreased visual acuity	<10–12 Gy maximum
Carotid artery	Occlusion	<20–23 Gy maximum
Acoustic neuroma	Symptomatic cranial nerve V and/or VII neuropathy	<12–13 Gy at tumor margin
	Hearing preservation	<12–13 Gy at tumor margin
Modiolus of cochlea	Hearing preservation	<4–5 Gy maximum
Cochlea	Hearing preservation	<6 Gy maximum
Spinal cord (RTOG 06-31)	Symptomatic myelopathy	0.35 ml <10 Gy[b] 0.035 ml <14 Gy[b]
Cauda equina (RTOG 06-31)	Symptomatic neuritis	<16 Gy maximum[b] 5 ml <14 Gy[b]
Spinal cord (conservative)	Symptomatic myelopathy	<8–10 Gy maximum
Thecal sac (conservative)	Symptomatic myelopathy	<10–14 Gy maximum

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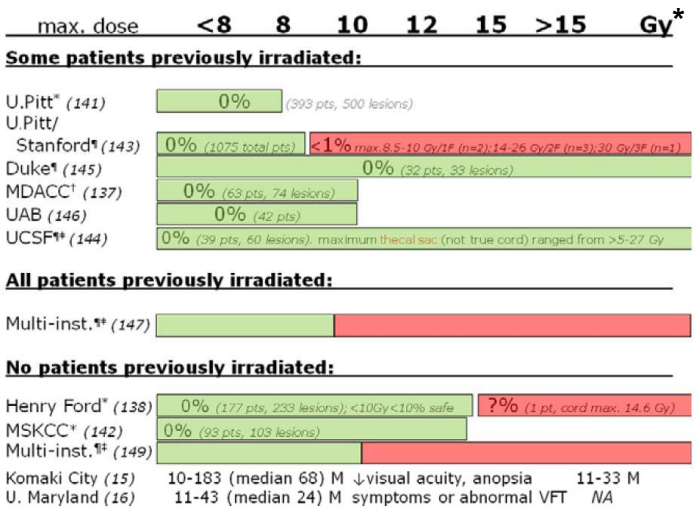
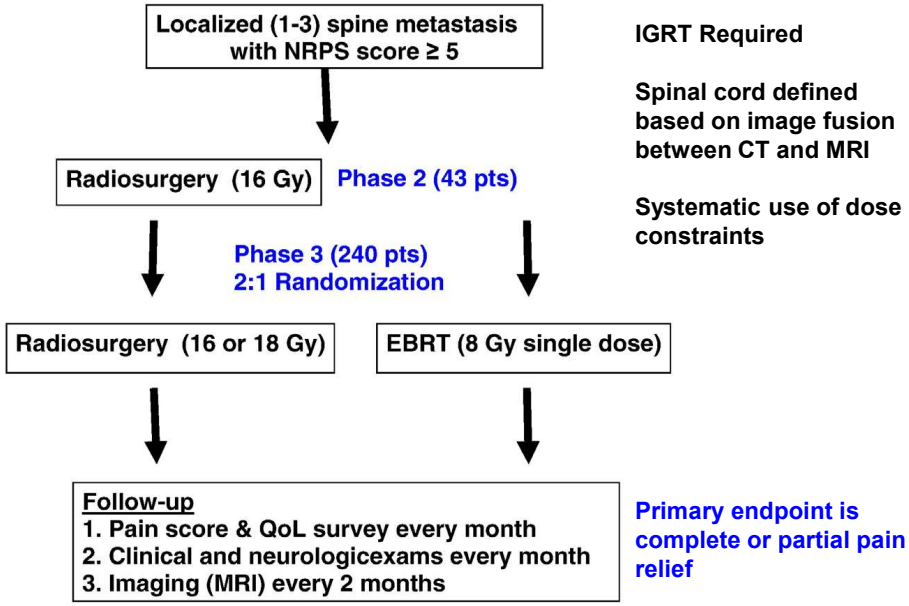
Risk of Spinal Myelopathy



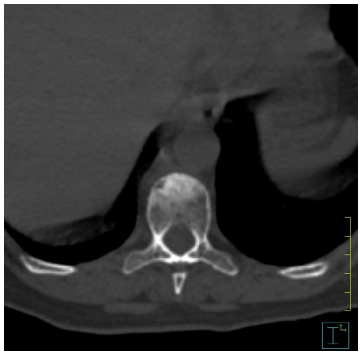
RTOG 0631 –Phase II/III study of image-guided radiosurgery /SBRT for localized spine metastases



Spine Planning

MR carefully fused to CT
Delineate cord and canal

Generally single fraction, occasionally up to 3
Almost always IMRT



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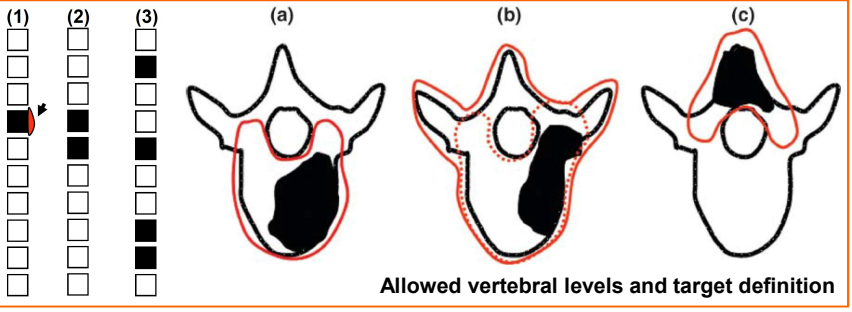
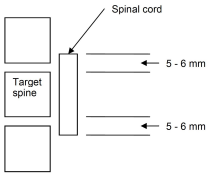
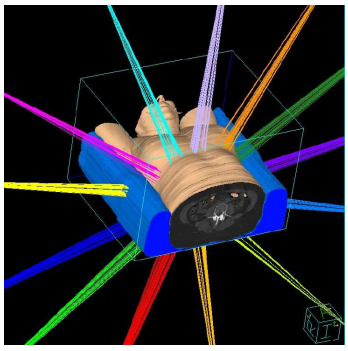


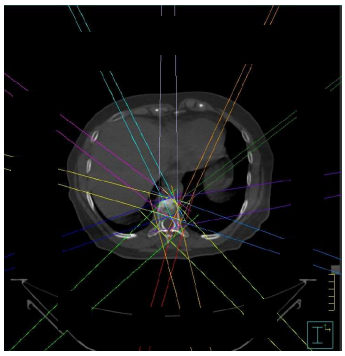
Allowed vertebral levels and target definition



Serial Tissue	Volume	Volume Max (Gy)	Endpoint (≥ Grade 3)
Spinal Cord	<0.035 cc <0.35cc <1.2 cc (SBRT only)	14 Gy 10 Gy 7 Gy (SBRT only)	myelitis
Cauda Equina	<0.035 cc <5 cc	16 Gy 14 Gy	neuritis
Sacral Plexus	<0.035 cc <5 cc	18 Gy 14.4 Gy	neuropathy

Spinal cord definition and constraints





Spine Planning

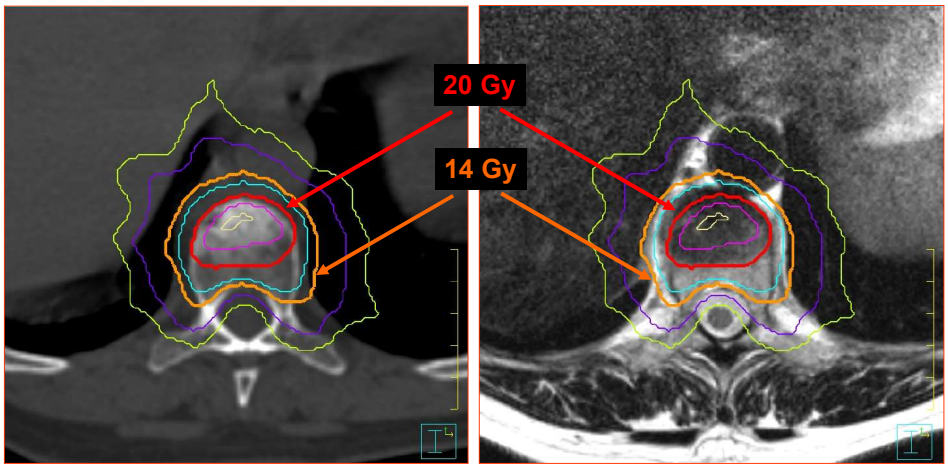
Multiple coplanar beams / VMAT

Spinal Cord defined 6 mm above and 6 mm below target vertebral body

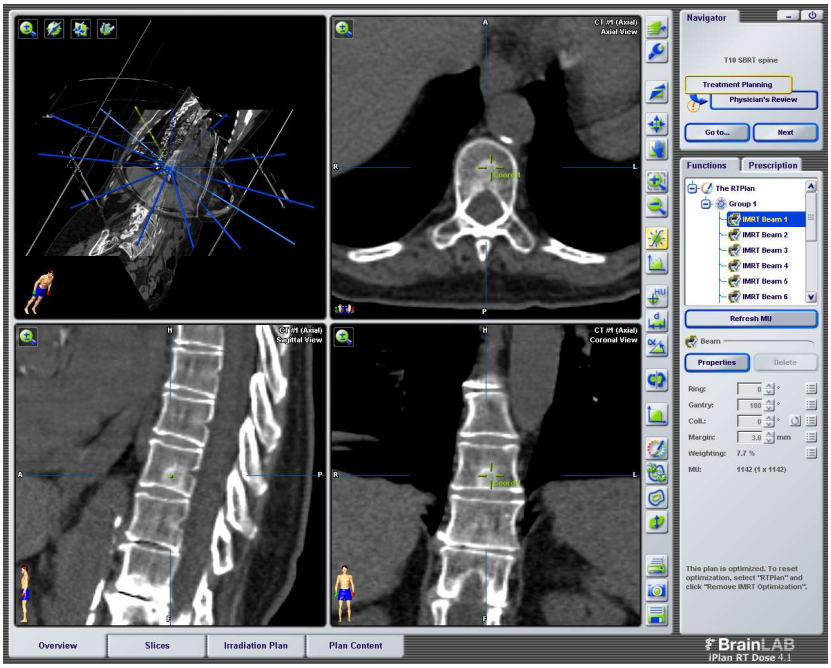
Cord constraints:

- **Max point dose 14 Gy**
- **<0.35 cc receives 10 Gy**
- **<1.2 cc receives 7 Gy**

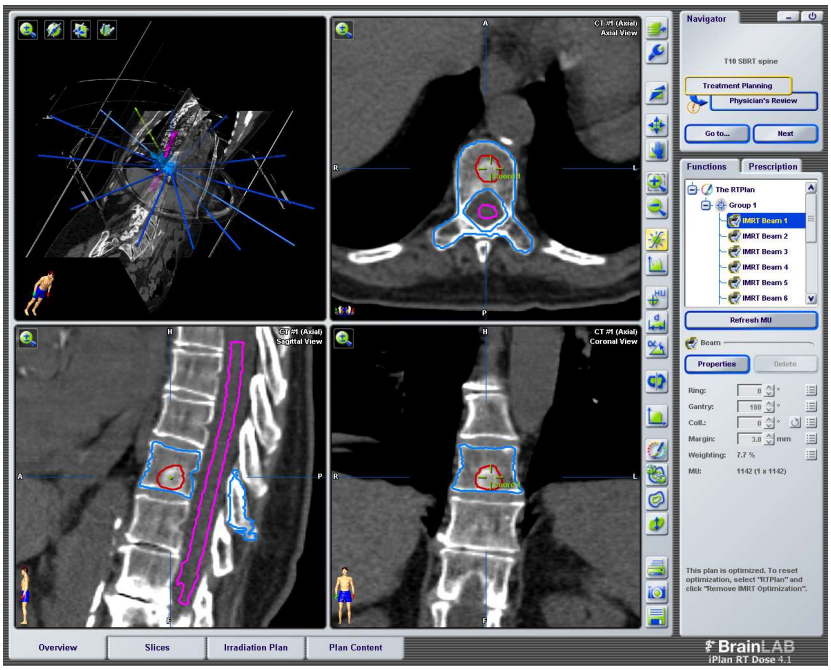
Dose Distribution



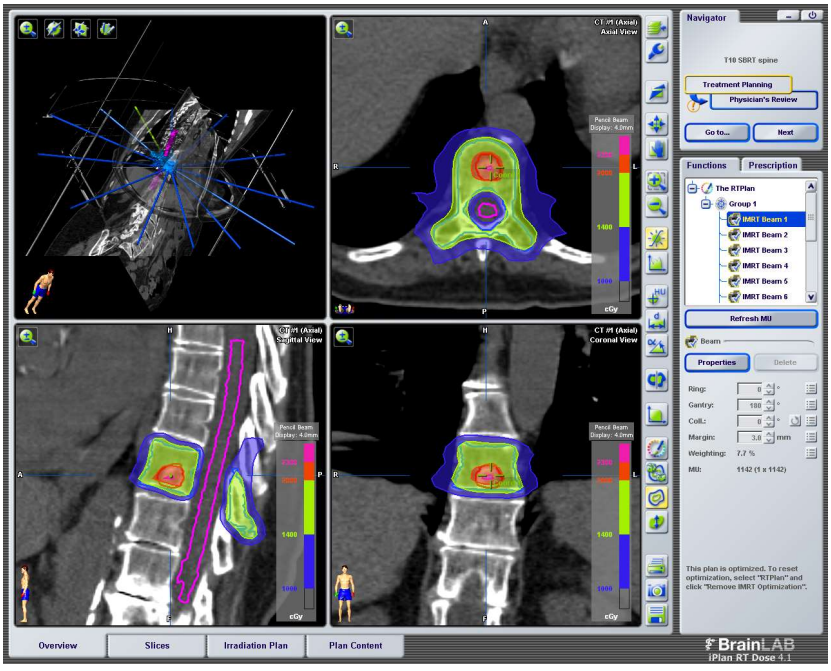
Spine SRS



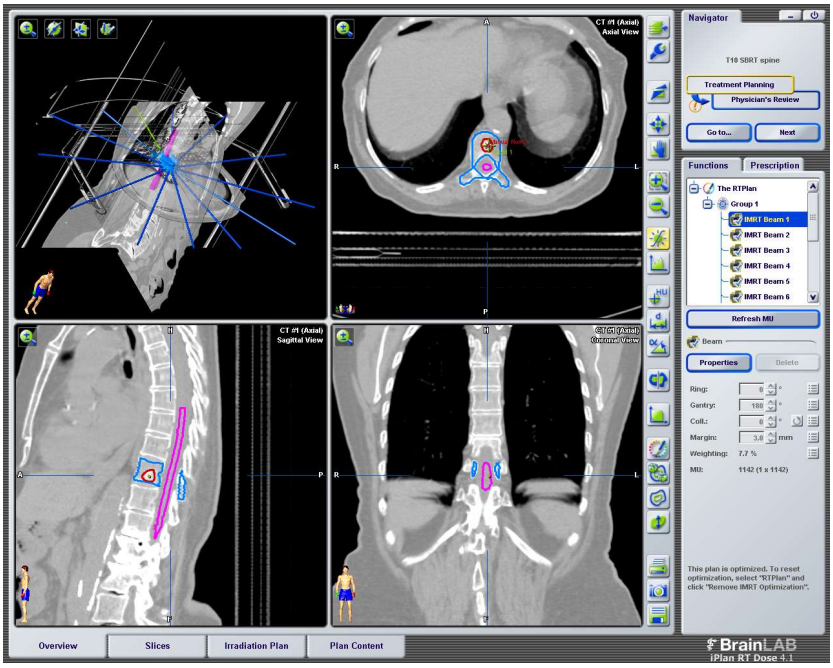
Spine SRS: GTV (red), CTV (blue)



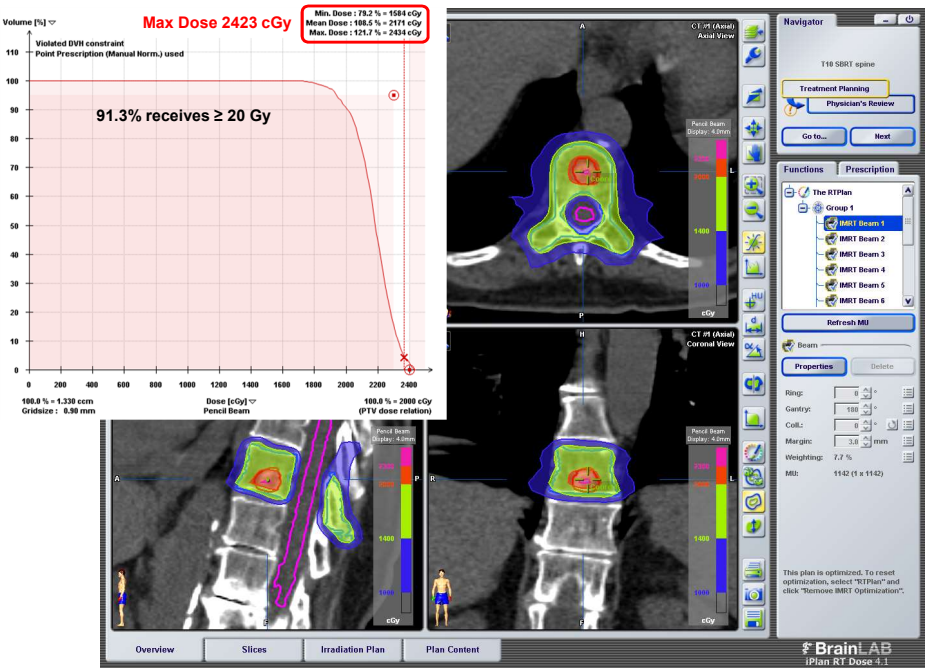
Spine SRS: 20 Gy to GTC, 14 Gy to CTV



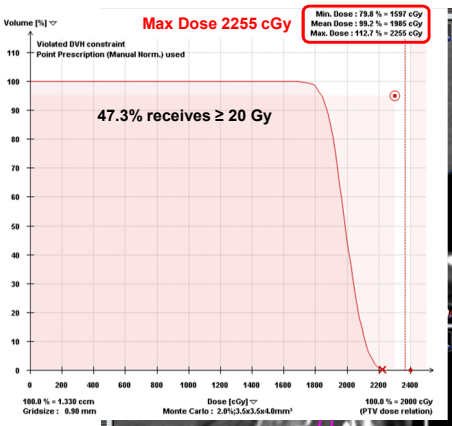
4DCT??? Motion Management??? Dose Algorithm???



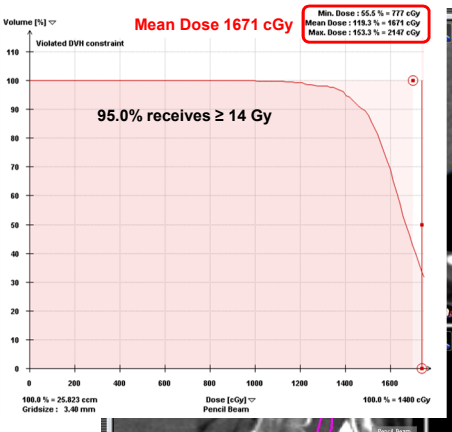
GTV - Pencil Beam



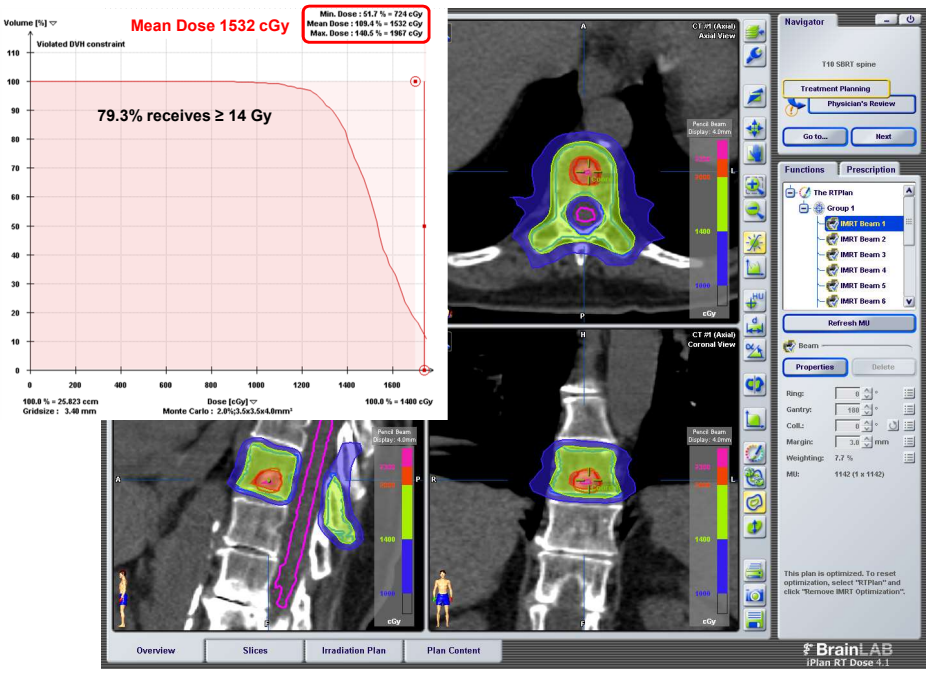
GTV - Monte Carlo



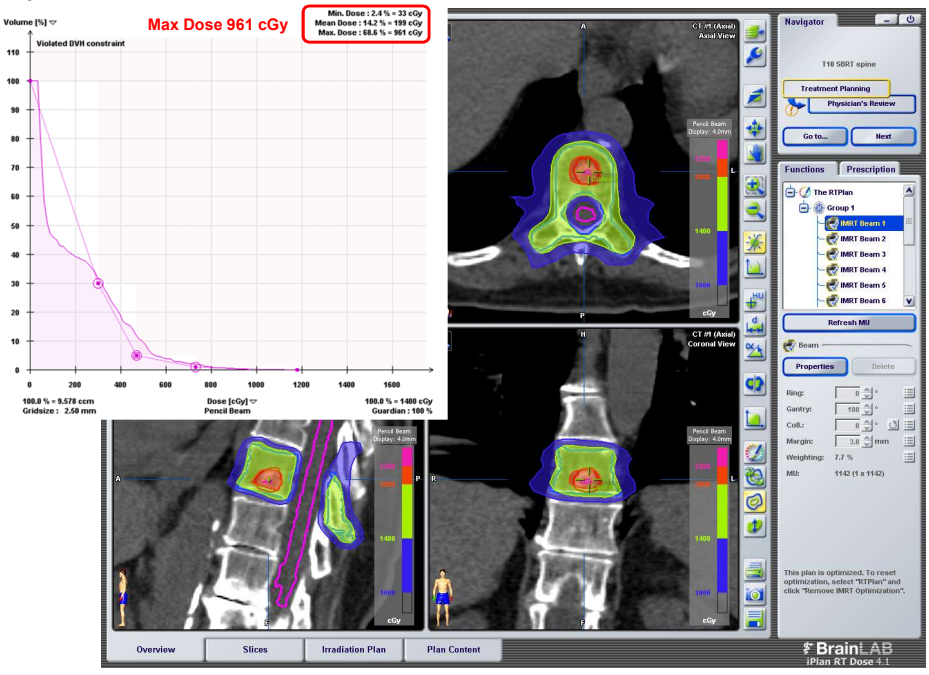
CTV - Pencil Beam



CTV – Monte Carlo



Spinal Cord - Pencil Beam



Spinal Cord – Monte Carlo

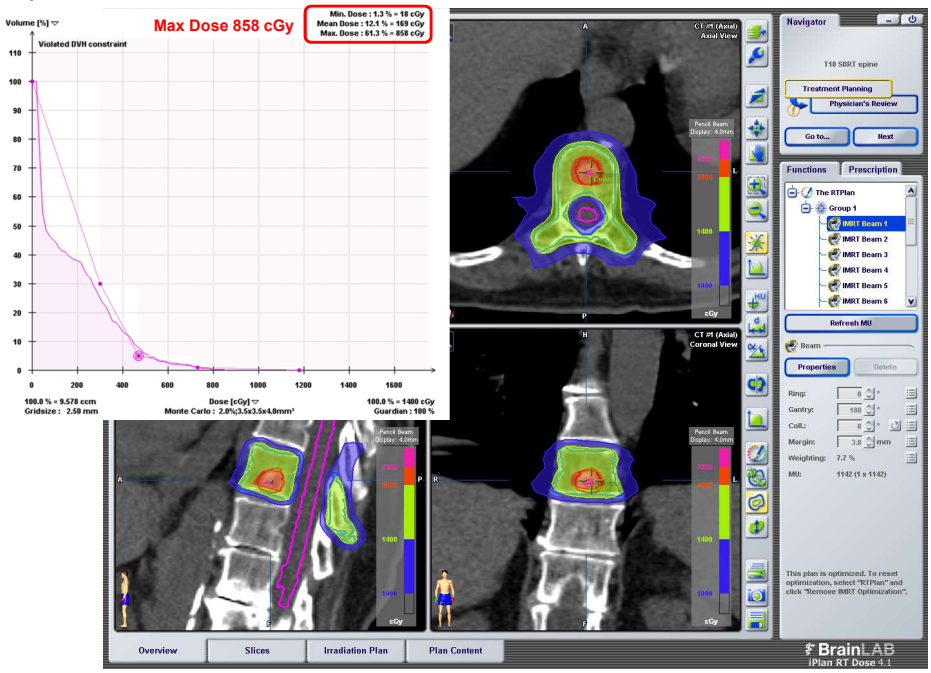
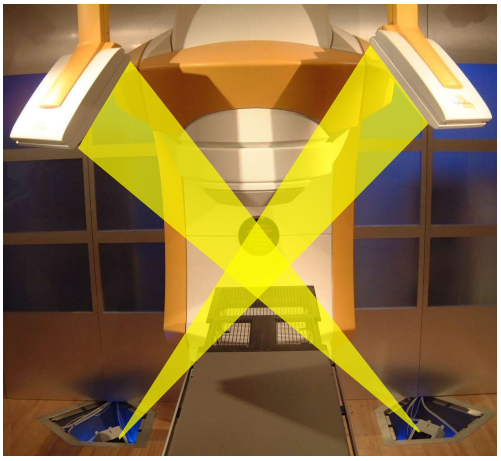
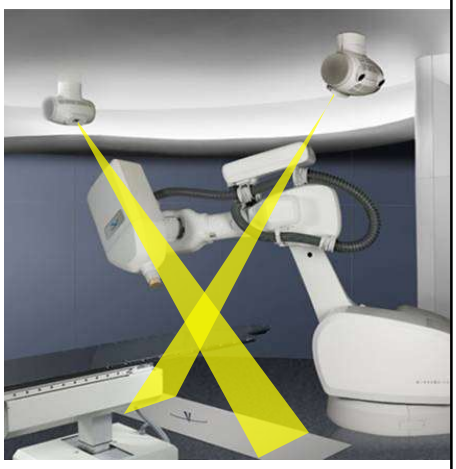


Image Guidance for Spine is Essential

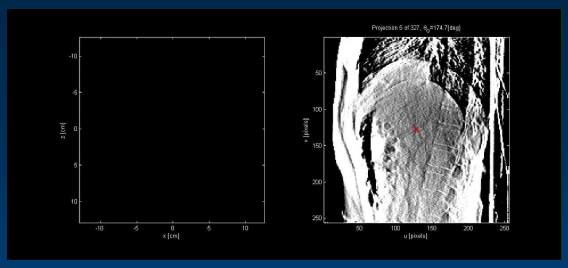


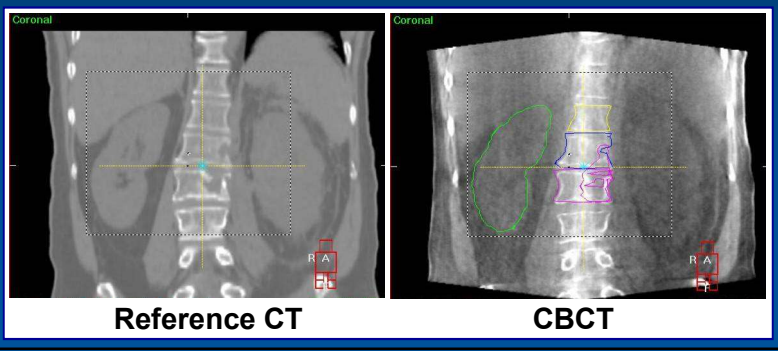
BrainLAB ExacTrac 6D
X-ray tubes recessed in floor
Flat panels mounted to ceiling

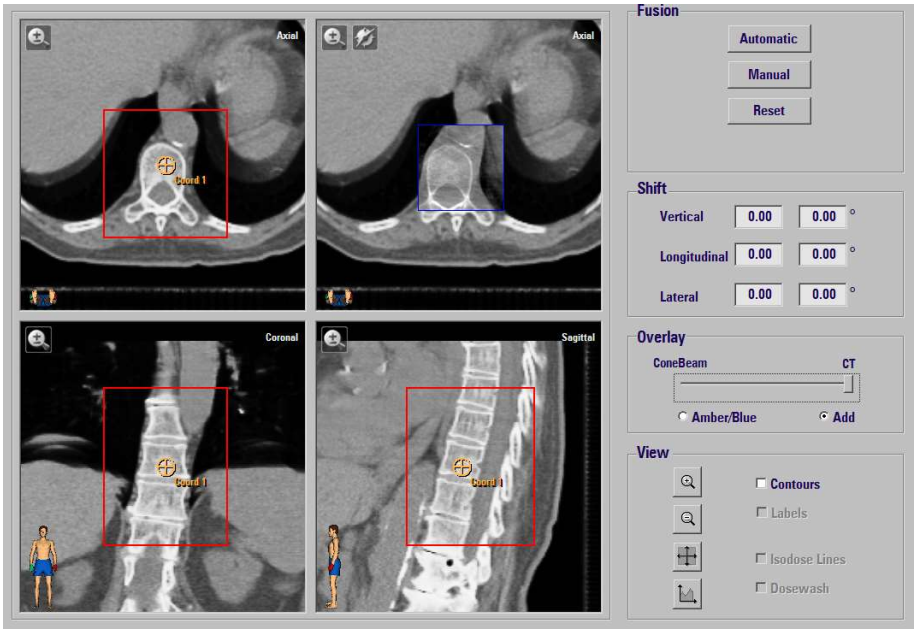


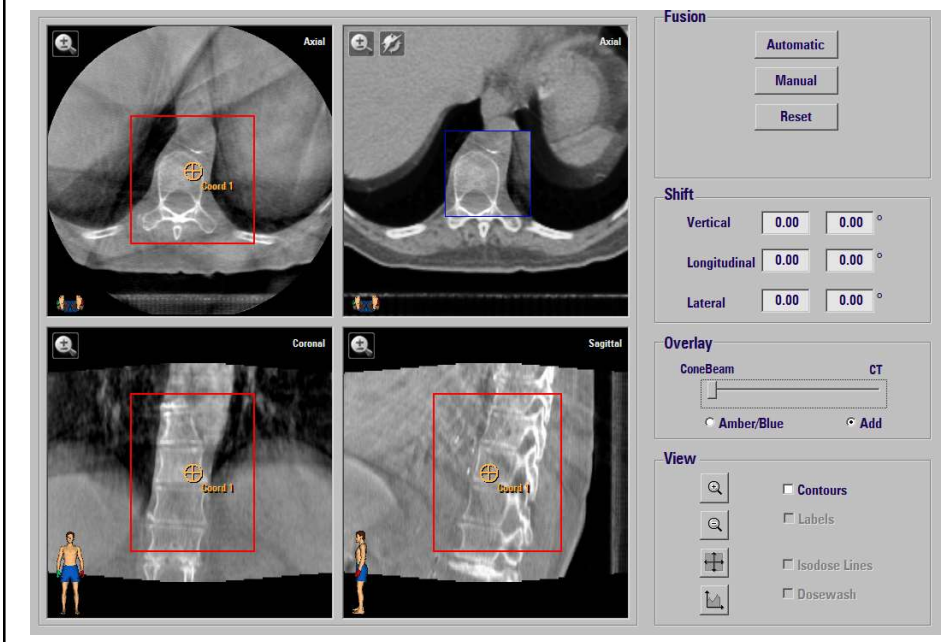
Accuray CyberKnife
X-ray tubes mounted to ceiling
Flat panels recessed in floor

CBCT for Spine Localization





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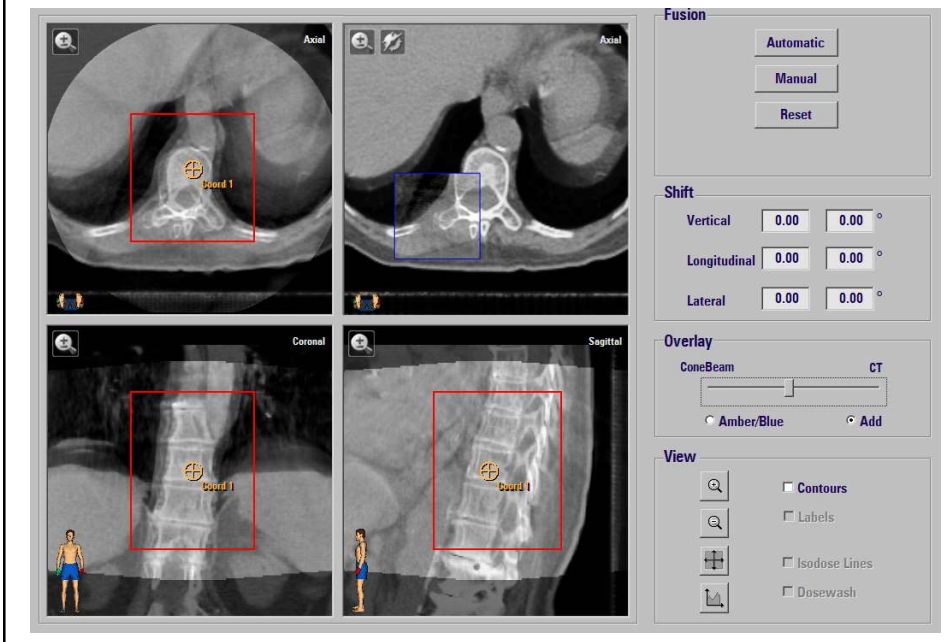
Dosewash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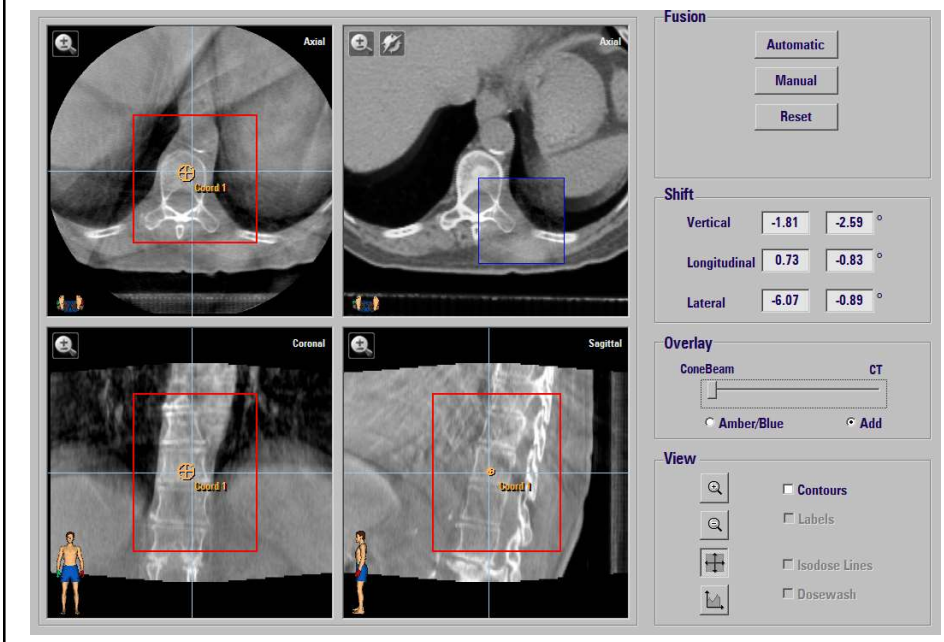
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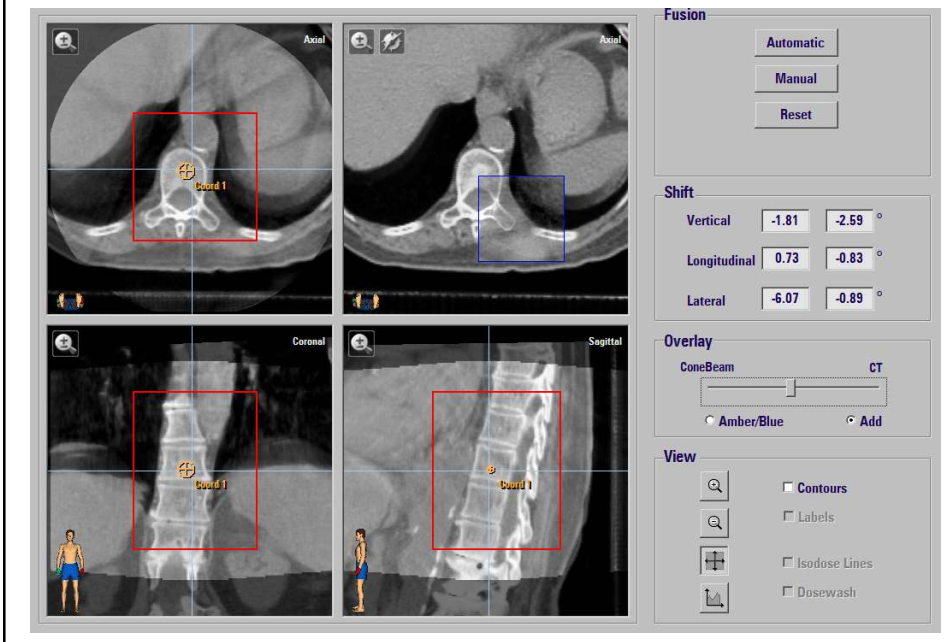
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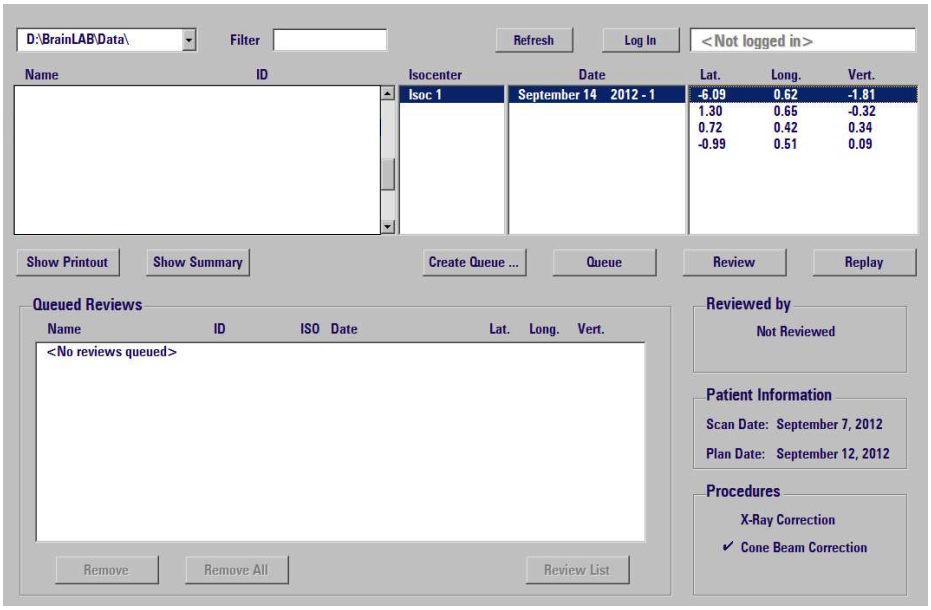
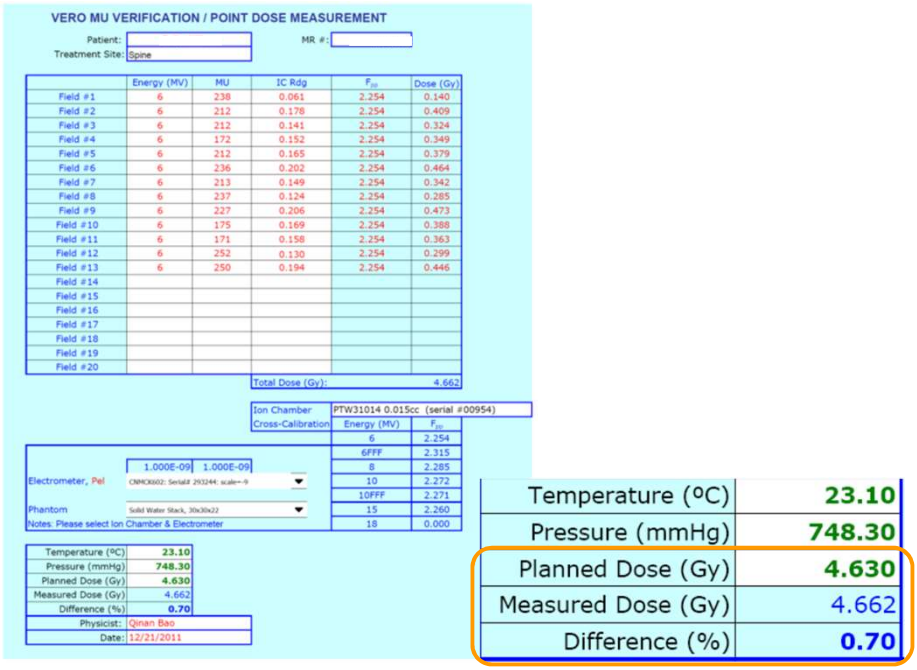
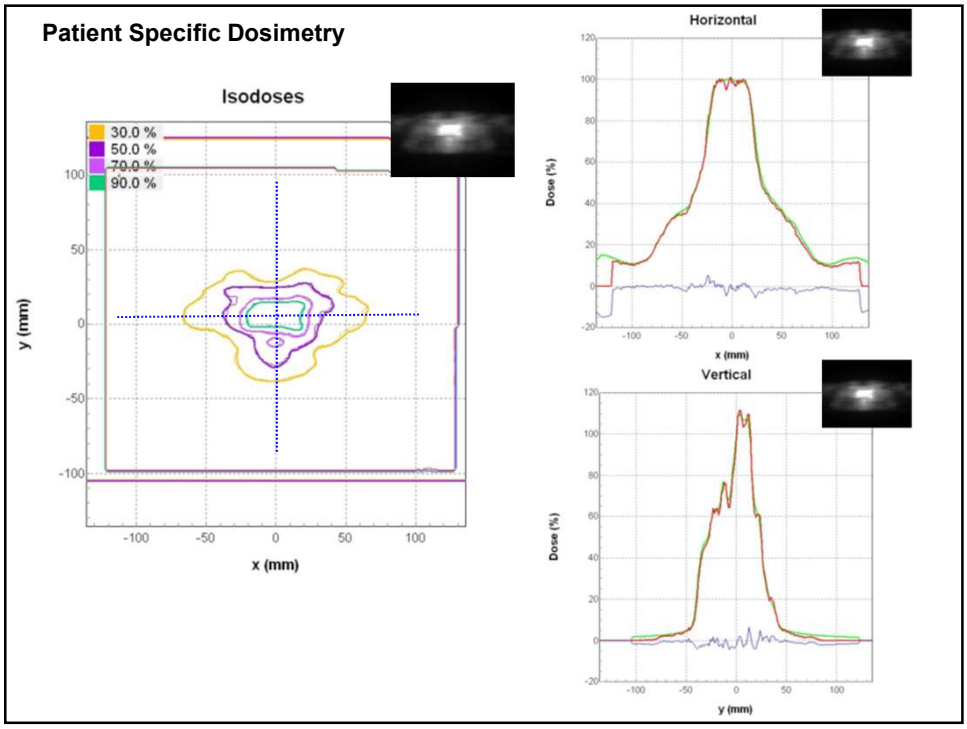
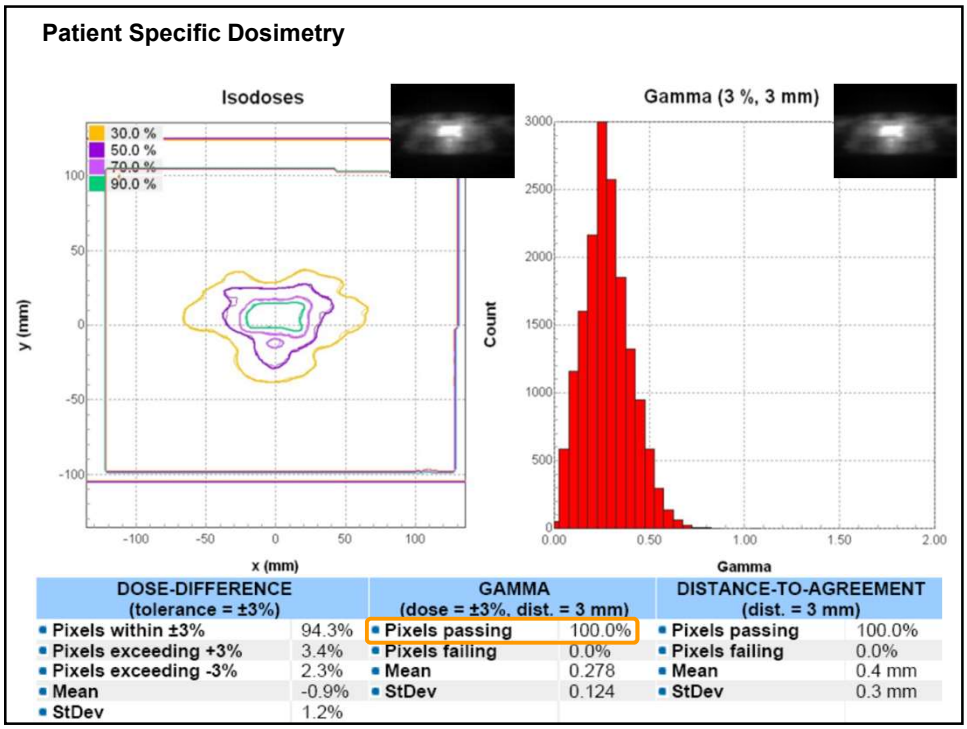
Intrafraction Motion



Patient Specific Dosimetry







DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±3%, dist. = 3 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)	
Pixels within ±3%	94.3%	Pixels passing	100.0%	Pixels passing	100.0%
Pixels exceeding +3%	3.4%	Pixels failing	0.0%	Pixels failing	0.0%
Pixels exceeding -3%	2.3%	Mean	0.278	Mean	0.4 mm
Mean	-0.9%	StDev	0.124	StDev	0.3 mm
StDev	1.2%				

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 16, NUMBER 1, 2015

Single-fraction spine SBRT end-to-end testing on TomoTherapy, Vero, TrueBeam, and CyberKnife treatment platforms using a novel anthropomorphic phantom

John J. Gallo,[1a] Isaac Kaufman,[2] Rachel Powell,[3] Shalini Pandya,[4] Archana Somnay,[5] Todd Bossenberger,[6,7] Ezequiel Ramirez,[8] Robert Reynolds,[8] Timothy Solberg,[9] Jay Burmeister,[6,7]

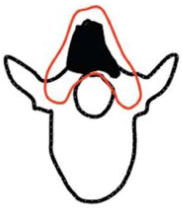
(a) / (d)

Mock targets contoured in a specialized spine phantom per RTOG 0631

- **(a) vertebral body,**
- **(b) all elements of a single vertebral level completely encircling the spinal cord,**
- **(c) the posterior spinous process,**
- **(d) two consecutive vertebral bodies**

Repeated in both thoracic and lumbar spine

(b)



(c)

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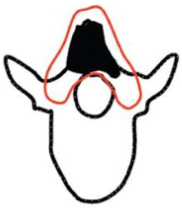
(a) / (d)

Planned and delivered on

Tomo:	**2 helical passes superposition/convolution**
Vero:	**13 coplanar IMRT beams Monte Carlo (thoracic) Pencil Beam (lumbar)**
TrueBeam:	**2 RapidArcs AAA Algorithm Repeat for flattened and FFF**
CyberKnife:	**3 fixed cones (10, 15, 25 mm) Ray Tracing**

(b)



(c)

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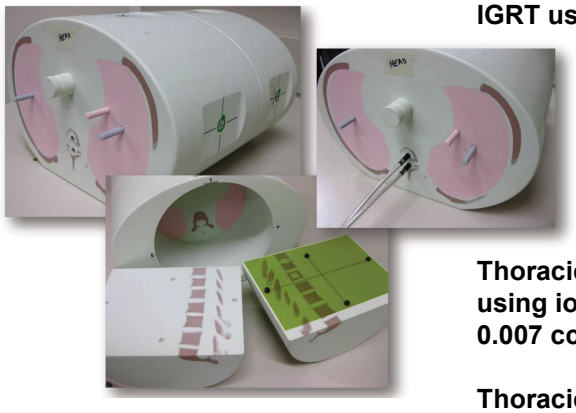
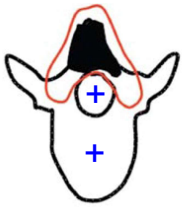


IGRT used for phantom setup



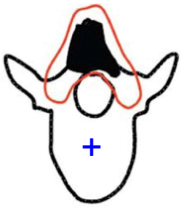
Thoracic targets and cord verified using ion chamber - Exradin A16 0.007 cc

Thoracic targets verified using laser cut GafChromic EBT film

TABLE 1. Thoracic ion chamber measurements in vertebral body.

Treatment Plan	*Ion Chamber Measurement (Gy)*	*Treatment Platform*				
		TomoTherapy	*Vero*	*TrueBeam (Flattened)*	*TrueBeam (FFF)*	*CyberKnife*
Plan A	Calculated Dose	16.5	20.6	16.5	16.3	17.9
	Measured Dose	16.4	21.1	17.0	16.5	18.5
	% Difference	-0.3	2.6	3.1	1.4	3.0
Plan B	Calculated Dose	16.6	20.8	16.4	16.5	21.8
	Measured Dose	16.6	21.5	16.3	16.6	22.4
	% Difference	0.0	3.2	-0.3	0.6	2.4
Plan D	Calculated Dose	16.2	21.2	16.0	16.2	20.4
	Measured Dose	16.5	21.5	16.1	16.3	20.6
	% Difference	2.2	1.4	0.6	0.8	0.7

For Plan C, the IC is not within the target, so measurements have significant uncertainty and were not reported



(c)

TABLE 2. Lumbar measurements with GAFCHROMIC EBT3 film with gamma analysis utilizing the dose criterion relative to the global maximum dose method.

Treatment Plan	*Global γ-analysis constraints w/ 10% threshold*	*Treatment Platform*				
		TomoTherapy	*Vero*	*TrueBeam (Flattened)*	*TrueBeam (FFF)*	*CyberKnife*
Plan A	3%/3 mm	100.0	100.0	100.0	100.0	100.0
	2%/2 mm	100.0	99.7	97.9	100.0	100.0
	1%/1 mm	81.3	61.8	77.6	84.3	95.4
Plan B	3%/3 mm	100.0	100.0	100.0	100.0	100.0
	2%/2 mm	99.9	98.7	98.5	99.3	99.3
	1%/1 mm	93.9	62.3	81.5	87.3	85.3
Plan C	3%/3 mm	100.0	100.0	100.0	100.0	100.0
	2%/2 mm	99.9	98.7	98.5	98.9	99.8
	1%/1 mm	93.0	65.2	86.3	85.0	75.4
Plan D	3%/3 mm	100.0	100.0	100.0	100.0	100.0
	2%/2 mm	99.7	100.0	96.9	99.8	100.0
	1%1 mm	87.3	87.5	89.1	90.5	90.4

TABLE 3. Lumbar measurements with GAFCHROMIC EBT3 film with gamma analysis utilizing the dose criterion relative to the pixel under analysis method.

Treatment Plan	*Local γ-analysis constraints w/ 10% threshold*	*Treatment Platform*				
		TomoTherapy	*Vero*	*TrueBeam (Flattened)*	*TrueBeam (FFF)*	*CyberKnife*
Plan A	3%/3 mm	100.0	99.9	100.0	100.0	99.5
	2%/2 mm	98.7	98.3	96.3	99.5	98.9
	1%/1 mm	71.7	49.8	64.7	72.8	84.2
Plan B	3%/3 mm	100.0	99.9	100.0	100.0	96.1
	2%/2 mm	99.9	96.0	97.8	98.9	93.3
	1%/1 mm	85.5	51.3	71.7	79.7	74.3
Plan C	3%/3 mm	100.0	100.0	100.0	100.0	99.2
	2%/2 mm	99.5	100.0	100.0	100.0	97.5
	1%/1 mm	77.1	47.2	81.3	79.2	53.2
Plan D	3%/3 mm	99.5	100.0	100.0	100.0	97.5
	2%/2 mm	96.7	99.8	96.2	99.6	95.1
	1%1 mm	80.7	75.5	81.8	82.1	79.6

TABLE 4. Treatment beam-on delivery times for various treatment platforms and target regions.

Treatment Machine	*Treatment Region*	*Plan & Delivery Time (min)* A	B	C	D	*Average*
TomoTherapy	Thorax	21.1	35.3	28.8	35.3	30.1
	Lumbar	24.8	20.6	27.9	40.8	28.5
				Total Average Delivery Time:		29 min 19 sec
Vero	Thorax	15.0	19.5	21.1	17.2	18.2
	Lumbar	16.8	24.5	21.1	17.2	19.9
				Total Average Delivery Time:		19 min 2 sec
TrueBeam (Flattened)	Thorax	9.6	11.1	7.6	10.2	9.6
	Lumbar	11.2	9.5	7.2	9.5	9.3
				Total Average Delivery Time:		9 min 30 sec
TrueBeam (FFF)	Thorax	4.3	5.5	3.5	4.1	4.3
	Lumbar	4.9	4.6	3.7	4.8	4.5
				Total Average Delivery Time:		4 min 24 sec
CyberKnife	Thorax	50.0	44.4	44.5	46.0	46.2
	Lumbar	43.9	46.9	40.8	42.6	43.5
				Total Average Delivery Time:		45 min 48 sec

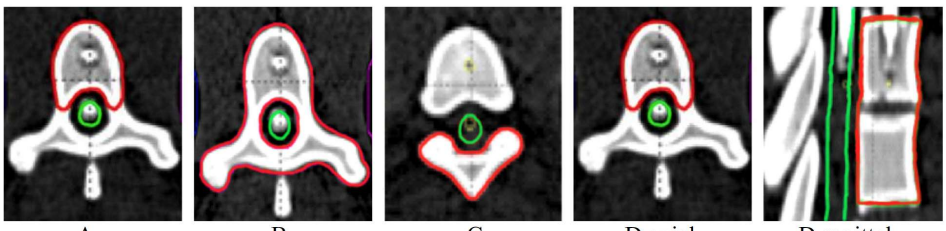
CK would be faster with IRIS collimator

Single fraction radiosurgery/stereotactic body radiation therapy (SBRT) for spine metastasis: A dosimetric comparison of multiple delivery platforms *J Appl Clin Med Phys* 2016; xx: 1–6

Adrian Nalichowski[1,2] | Isaac Kaufman[2] | John Gallo[2] | Todd Bossenberger[1] | Tim Solberg[3] | Ezequiel Ramirez[3] | Yulong Yan[3] | Julie Fredrick[4] | Tewfik Bichay[5] | Alan Mayville[5] | Jay Burmeister[1,2]

Single fraction SBRT plans designed for 4 targets for 4treatment modalities: RapidArc, Tomotherapy, CyberKnife, Vero

Plans prescribed to 16 Gy to cover 90% of the target volume using constraints from RTOG 0631



A B C D axial D sagittal

Repeated for thoracic and lumber levels

Single fraction radiosurgery/stereotactic body radiation therapy (SBRT) for spine metastasis: A dosimetric comparison of multiple delivery platforms *J Appl Clin Med Phys* 2016; xx: 1–6

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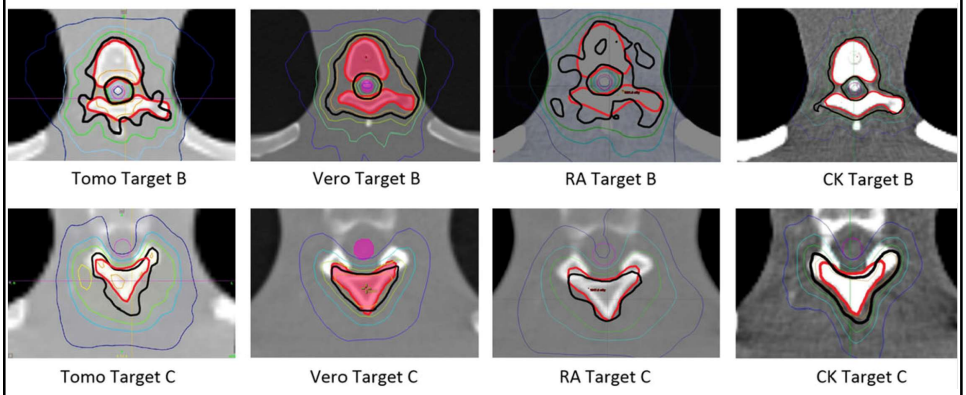
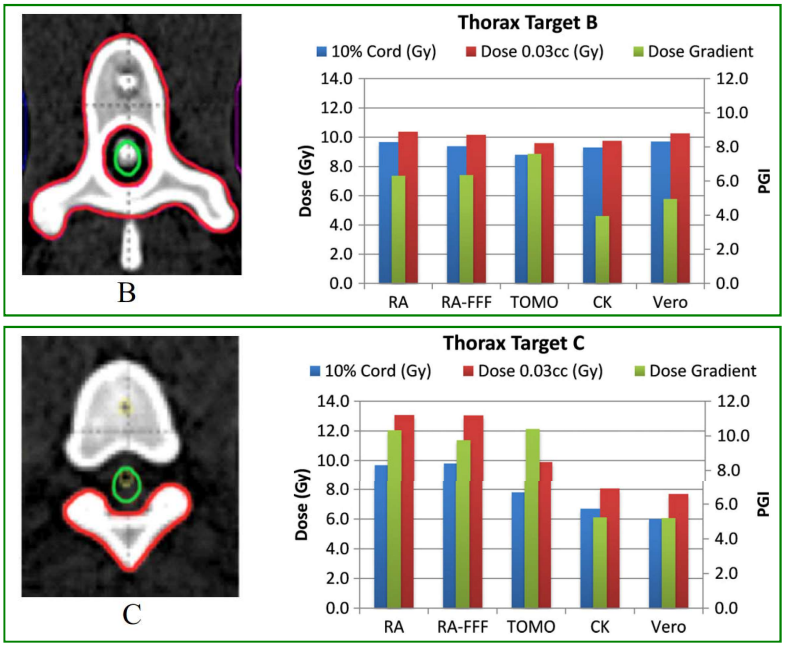
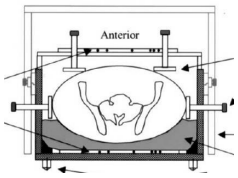




Lowest cord doses and sharpest falloff in CyberKnife and Vero plans, particularly for small targets

Clinical Results



- 93 patients and 103 spinal mets
- Solid Malignancy, No prior surgery, No compression, No instability, No prior XRT
- Single fraction 18 – 24 Gy, Cord limited to 14 Gy
- Actuarial local control rate 90% (median follow up of 15 months)
- **No Myelopathy**

Yamada et al, IJROBP 2008; 71(2):484-90
Yenice et al, IJROBP 2003; 55(3):583-93

- 230 mets in 177 patients
- 1-2 contiguous levels, ≤ 3 sites, no prior XRT, varying histology and spinal levels
- Single fraction 8 Gy - 18 Gy prescribed to 90% isodose line
- Median follow up 6.4 mo (range 0.5 – 49)
- **1 case of cord injury at 13 months**

Ryu et al, Cancer 2007; 109(3):628-36

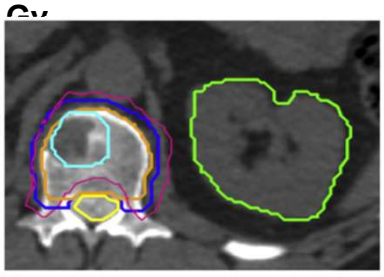
- Estimated that 10 Gy to 10% of the cord as defined 6mm above and below the target is safe

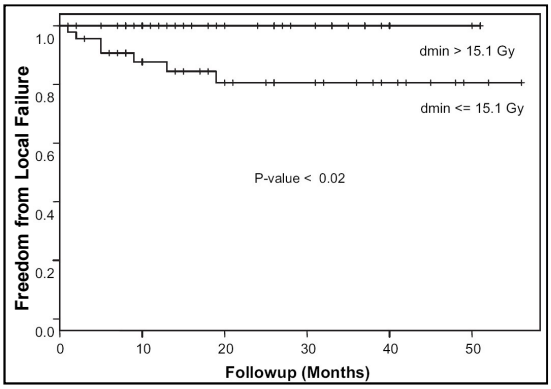
Spinal Cord Volume/Dose Relation in 86 Patients Who Survived Longer Than 1 Year, and a Presented Patient Who Had Long-Term Complications

	Average cord dose	Highest cord dose	Patient with complications
30% cord volume	6.2 ± 1.8 Gy	10.9 Gy	6.2 Gy
20% cord volume	7.2 ± 2.0 Gy	12.4 Gy	7.6 Gy
10% cord volume	8.6 ± 2.1 Gy	13.0 Gy	9.6 Gy
5% cord volume	9.7 ± 2.3 Gy	14.9 Gy	11.1 Gy
1% cord volume	10.7 ± 2.3 Gy	15.8 Gy	13.0 Gy
Maximum point dose	12.2 ± 2.5 Gy	19.2 Gy	14.6 Gy

Dose Response to Spine SRS

~~91 lesions in 79 patients~~
Prescribed 18-24 Gy
Cord constrained to14 Gy





Int. J. Radiation Oncology Biol. Phys., Vol. 77, No. 4, pp. 1282–1287, 2010

0360-3016/$–see front matter

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CORRELATION OF LOCAL FAILURE WITH MEASURES OF DOSE INSUFFICIENCY IN THE HIGH-DOSE SINGLE-FRACTION TREATMENT OF BONY METASTASES

D. Michael Lovelock, Ph.D.,* Zhigang Zhang, Ph.D.,† Andrew Jackson, Ph.D.,*
Jennifer Keam, M.D.,‡ Justin Bekelman, M.D.,§ Mark Bilsky, M.D.,‖ Eric Lis, M.D.,¶
and Yoshiya Yamada, M.D.‡

Spinal SRS Complications
5 reported cases of myelopathy in de novo SRS cases

# Fractions	Max Cord Dose	Dose (0.1 cc)	
1	10.6 Gy	8.5 Gy	Gerszten et al, Neurosurg, 2008
1	13.1 Gy	6.9 Gy	Gerszten et al, Neurosurg, 2008
1	14.6 Gy	13.7 Gy	Ryu et al, Cancer, 2007
2	25.6 Gy	24.7 Gy	Gibbs et al, Radiother Onc, 2007
3	30.9 Gy	27.8 Gy	Dodd et al, Neurosurg, 2006

Int. J. Radiation Oncology Biol. Phys., Vol. 77, No. 2, pp. 548–553, 2010

0360-3016/$–see front matter

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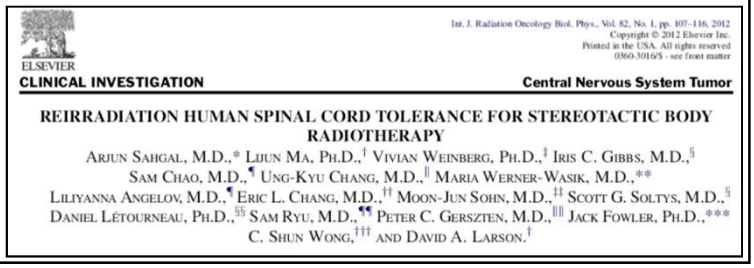
CLINICAL INVESTIGATION Spinal Cord

SPINAL CORD TOLERANCE FOR STEREOTACTIC BODY RADIOTHERAPY

Arjun Sahgal, M.D.,* Lijun Ma, Ph.D.,† Iris Gibbs, M.D.,‡ Peter C. Gerszten, M.D.,** Sam Ryu, M.D.,§ Scott Soltys, M.D.,‡ Vivian Weinberg, Ph.D.,¶ Shun Wong, M.D.,§§ Eric Chang, M.D.,†† Jack Fowler, D.Sc., Ph.D.,‡‡ and David A. Larson, M.D., Ph.D.†

Spinal SRS Complications
5 reported cases of myelopathy in patients with prior irradiation

Spine tumor location and target volume (cc)	Prior EBRT thecal sac dose (Gy)/fx (BED) (nBED)	SBRT Retreatment tumor dose(Gy)/fx/ prescription isodose (%)	Time interval to SBRT (months)	Time to RM after retreatment (months)	Follow-up Post-SBRT (months)	Status last follow-up
T5 (10.7)	40/22 ($76\ Gy_2$) ($38\ Gy_{2/2}$)	20/2/80	81	6	55	Alive/ Para-plegic
T1 (18.8)	25.2/28 ($37\ Gy_2$) ($18.3\ Gy_{2/2}$)	21/2/69	70	5	29	Alive/ Chair bound
T11–T12 (119)	21.2/5 ($66\ Gy_2$) ($33\ Gy_{2/2}$)	14/1/100	11*	3	17	Alive/ Para-plegic
C1/C2 (31.5)	51.9/28 ($100\ Gy_2$) ($50\ Gy_{2/2}$)	33/3/83	18	8	11	Alive/ Sensory deficit
T10 (46.4)	43.2/15 ($105\ Gy_2$) ($52.5\ Gy_{2/2}$)	16/1/88	12	3	3	Dead



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0360-3016/$ - see front matter

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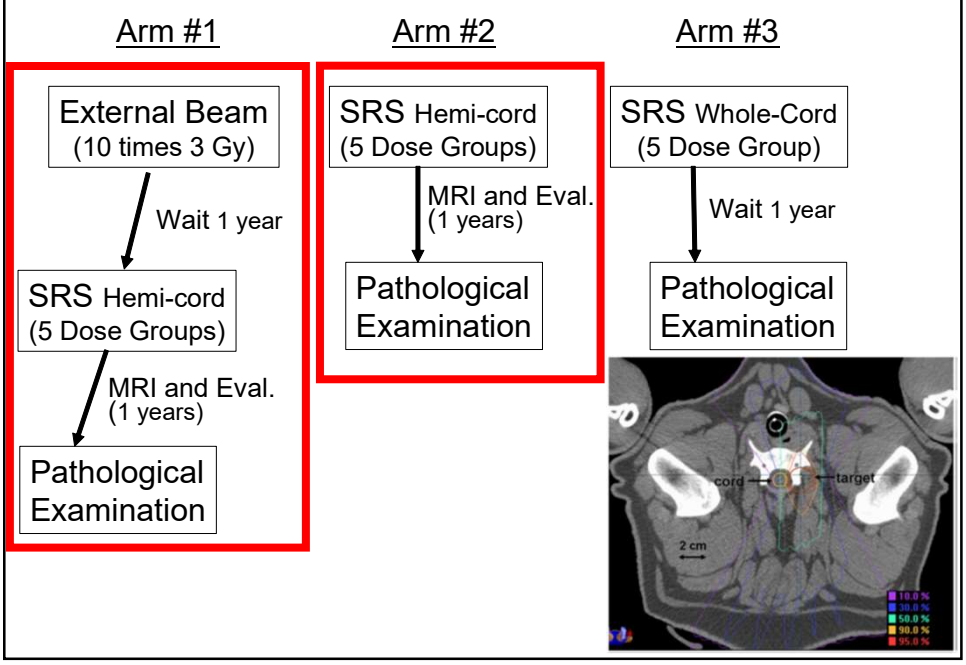
CLINICAL INVESTIGATION Central Nervous System Tumor

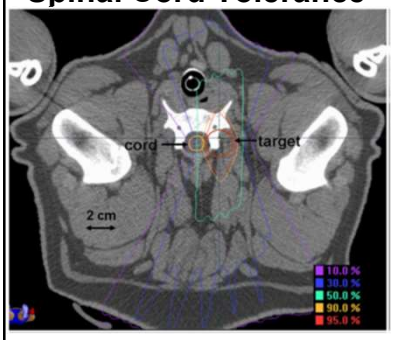
REIRRADIATION HUMAN SPINAL CORD TOLERANCE FOR STEREOTACTIC BODY RADIOTHERAPY

Arjun Sahgal, M.D.,* Lijun Ma, Ph.D.,† Vivian Weinberg, Ph.D.,‡ Iris C. Gibbs, M.D.,§ Sam Chao, M.D.,¶ Ung-Kyu Chang, M.D.,‖ Maria Werner-Wasik, M.D.,** Liliyanna Angelov, M.D.,¶ Eric L. Chang, M.D.,†† Moon-Jun Sohn, M.D.,‡‡ Scott G. Soltys, M.D.,§ Daniel Létourneau, Ph.D.,§§ Sam Ryu, M.D.,¶¶ Peter C. Gerszten, M.D.,‖‖ Jack Fowler, Ph.D.,*** C. Shun Wong,††† and David A. Larson.†

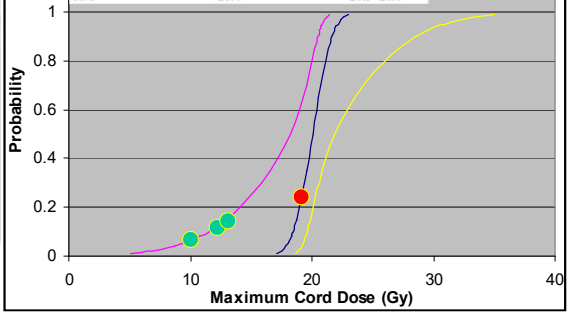
Swine SRS Spinal Cord Study – 25 animals per arm



Spinal Cord Tolerance



Probability	Dose (Gy)	95% Confidence interval (Gy)
0.01	17.4	5.8–18.8
0.05	18.2	9.8–19.3
0.10	18.6	11.9–19.6
0.50	20.0	18.3–21.7
0.90	21.4	20.3–28.1



Int. J. Radiation Oncology Biol. Phys., Vol. 79, No. 1, pp. 226–232, 2011

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BIOLOGY CONTRIBUTION

SPINAL CORD TOLERANCE TO SINGLE-FRACTION PARTIAL-VOLUME IRRADIATION: A SWINE MODEL

Paul M. Medin, Ph.D.,* Ryan D. Foster, Ph.D.,* Albert J. van der Kogel, Ph.D.,†
James W. Sayre, Ph.D.,‡§ William H. McBride, D.Sc.,¶ and Timothy D. Solberg, Ph.D.*

What about prior irradiation?

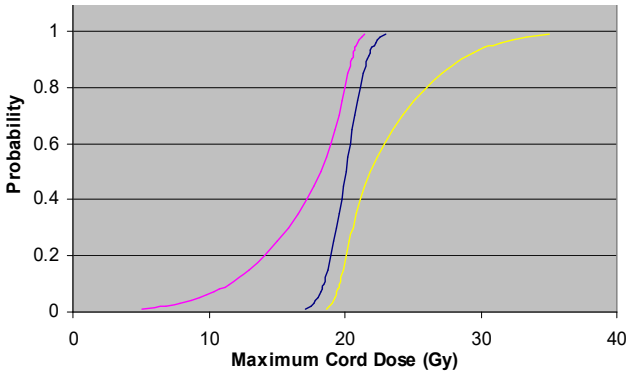
Biology Contribution

Spinal Cord Tolerance to Reirradiation With Single-Fraction Radiosurgery: A Swine Model

International Journal of Radiation Oncology biology • physics

Paul M. Medin, Ph.D.,* Ryan D. Foster, Ph.D.,† Albert J. van der Kogel, Ph.D.,‡ James W. Sayre, Ph.D.,¶ William H. McBride, D.Sc.,§ and Timothy D. Solberg, Ph.D.‖

Int J Radiation Oncol Biol Phys, Vol. 83, No. 3, pp. 1031–1037, 2012



Arm #1

External Beam (10 times 3 Gy)

Wait 1 year

SRS Hemi-cord (5 Dose Groups)

MRI and Eval. (1 years)

Pathological Examination

No Difference

1. RTOG 0631:

a) Permits treatment of three contiguous vertebral bodies
b) Randomizes patients to one or three fractions
c) Has a primary endpoint of local control
d) Always requires treatment of the entire vertebral body
e) Specifies a maximum cord dose of 14 Gy

Answer: Specifies a maximum cord dose of 14 Gy

Refs: RTOG 0631

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2. Spinal SRS ….

a) Has never been performed without image guidance
b) Is only delivered in a single fraction
c) Should never be performed if the patient has received prior irradiation
d) Is delivered the fastest on a Tomotherapy unit
e) Is delivered the slowest on a CyberKnife unit

Answer: CyberKnife delivery is significantly longer than that on conventional linacs or Tomotherapy systems

Ref: Nalichowski et al, JACMP, 2016

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Thank You

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UCSF University of California San Francisco

SEAAPM SYMPOSIUM & SCIENTIFIC MEETING FEB. 23-25, 2017